NEW WORLD VISTAS
AIR AND SPACE POWER FOR THE 21ST CENTURY

SPACE TECHNOLOGY VOLUME

Executive Summary

An Investment Strategy for the Air Force in Space Technology for the Next Twenty Years

Vision

The Space Technology Panel's recommendations for technology investments derive from a vision of the Air Force in space in the 21st century, in which the Air Force has achieved *survivable, on demand, real time, global presence that is affordable.* This vision represents a *revolutionary* increase in capabilities for the Air Force and is achievable with targeted Air Force technology investments and adaptation of commercial developments. These technology investments will enable the US to maintain military superiority by the exploitation of space through four themes:

- Global Awareness
- Knowledge on Demand
- Space Control
- Force Application

The Current Situation in Space

Space will continue to be the proverbial high ground for the foreseeable future. Operation Desert Storm showed that space assets integrated with air, ground, and sea assets can play a critical role as force enhancers in fighting and winning conflict. Senior Air Force leadership[1] asserts that "space systems signal America's stature as a world power and aerospace nation. Control of space and access to it are fundamental to economic and military security. Ask the 20 foreign countries who will have space capabilities by the year 2000: a presence in space implies influence, power and security."

The space enterprise can be divided roughly into four areas:

- Launch systems
- Spacecraft bus systems
- Spacecraft payload systems
- Spacecraft operations

In the area of launch systems, despite the recent development of small launch vehicles, US launch capability is dominated by an old, unresponsive, and relatively expensive set of launchers. Foreign launch systems have taken a substantial fraction of the world market, and the number of countries able and willing to launch payloads is continuing to increase. In the area of spacecraft bus technology, the US is in a leading position; the one major area where other countries have taken the lead is in spacecraft propulsion, where US technology is behind what has been

1. Hon. Sheila E. Widnall, Secretary of the Air Force, September 1993

accomplished in the former Soviet Union. The US is still leading in the integration and operation of spacecraft payload systems both from the component level into spacecraft and in the development of constellations of spacecraft. *This leading position is due to previous government investments in research and development in space technology*; maintaining this lead in the future will depend on the technology investments that the US government *and* private sector make today.

The reduction of resources available to the DoD in the post-Cold War era means that DoD investment in space technologies and space systems must be firmly rooted in the goal of affordable systems. To this end, the DoD must plan its technology investment with a clear view of technological advances in the commercial world. It is undesirable and unnecessary for the DoD to develop every technology for its space systems on its own. There are many technologies that the commercial sector will develop that the military can adapt for its use with minimal investment. On the other hand, there will always be unique requirements for military systems that necessitate the use of technologies that have no commercial application, that push the performance limits of dual-use technologies, or whose timescale and risk are not attractive to the commercial sector. The DoD should carefully target its investments in technology to achieve the highest possible return. Technologies that are candidates for DoD investments fall into one of three possible categories:

- Revolutionary technologies in which the DoD must invest vigorously, because they are critical to the military mission and have little or no application in the commercial sector; without DoD investment, these technologies will not advance. These technologies will enable a *substantial increase in the exploitation of space* by the DoD. They will enable functions that are currently unaffordable or technically impossible.
- Evolutionary technologies in which the DoD should invest, because they are similarly critical to the military mission and have little or no commercial application. These technologies will enable gradual advances that over time can significantly improve the performance or reduce the life-cycle costs of military systems.
- Technologies in which little DoD investment is required, because they will be led by the commercial sector. In these areas, the DoD should carefully monitor the progress that industry is making and invest only to the level necessary to adapt commercial technologies to the military mission.

The DoD should not underestimate the benefits of a healthy synergism between military and commercial research and development.

The Air Force's investment in space technology has fallen in recent years both as a fraction of Total Obligation Authority (TOA) and as a fraction of spending on research and development. The inception of the Strategic Defense Initiative Organization (SDIO) in 1983 brought the primary Air Force space technology programs under the SDIO umbrella. During the heyday of SDIO, total DoD investment in space technology programs was more than $500M/year. The primary emphasis during this time was highly survivable space technology development and demonstration. In addition, major programs were initiated under the SDIO umbrella in active

and passive space sensors, radiation-hardened electronics, advanced high-data-rate communications, high-efficiency and high-power solar arrays, and high-density power storage technologies along with cryocoolers and other related structural technologies. Great emphasis was placed on technologies and systems that were highly survivable against a variety of threats including laser, nuclear, and microwave effects. The evolution of SDIO into the Ballistic Missile Defense Office (BMDO) and the subsequent program direction to address theater missile defense had a negative impact on the space technology development budget and, as a result, space technology investment has decreased from $500 M/year to $200M/year. This dramatic decrease in space technology development investments will have a serious impact on the dominant position of the US in space systems development, both commercial and military, for years to come.

Air Force investment in space technology is grossly inadequate. The current situation is similar to the state of affairs earlier in this century when the US lead in aircraft technology faltered and a sustained effort was required to recapture that lead. The exploitation of space for military advantage requires aggressive and continuous investment.

Space Technology and Space Systems in the Future

In the next ten to twenty years, the commercial world will see the development of four types of space-based systems that will be available to both friendly and unfriendly nations, corporations, and individuals on a worldwide basis. These systems will provide commercial services but will also be militarily useful. In addition, these systems will either involve other countries that build or purchase them or will involve international consortia of investors. These systems will lead to the growth of new service industries based around their use that will be economically powerful. (A current example is the Global Positioning System (GPS); the growth of civilian users, including the FAA, is now creating a dilemma about the compatibility of easy access to precision GPS with the DoD's need to maintain a competitive military advantage.)

Four types of commercial services that will be available are:

- Global positioning and navigation services. While the DoD already has GPS, other countries are developing equivalent systems or augmenting the existing one; similar capabilities will be available through the development of personal communication systems. They will enable navigation with an accuracy of at least several tens of meters.
- Global communication services. Several systems have already been proposed, such as Iridium, Globalstar, and Inmarsat-P. These systems will provide universal communications services between mobile individuals to almost any location on the surface of the Earth. These systems will work transparently with local cellular systems and will enable rapid telecommunications development in underdeveloped parts of the world.
- Information transfer services. These services will enable data transfer between any two points on the surface of the Earth at rates ranging from a few kilobits per second to gigabits per second. Proposed systems include Orbcomm, Spaceway, Cyberstar, and Teledesic. Individual users will be able to access large amounts of data on demand. Direct TV from direct broadcast satellites is a harbinger of what will be possible.

- Global reconnaissance services. These services will provide commercial users multispectral data on almost any point on the surface of the Earth with meter-scale resolution. This data will span the range from the radio frequencies (RF) to the infrared (IR) through the visible into the ultraviolet (UV). This information will be available within hours of a viewing opportunity and on the order of a day from the time of a request. Proposed systems include improvements to the French SPOT as well as Orbimage, World View, and various types of radar satellites.

Each of these services will be part of the global infosphere. It will be possible for persons of means to locate themselves on any point on the Earth, communicate both by voice and computer to other points on the Earth, and have a good picture of the local environment. Both the services and the technologies that enable them will be commercially available all over the world. Given the enormous magnitude of the commercial market, military and NASA communications will have to be fully integrated with and technologically dependent on the exploding market- driven communications technologies.

Nevertheless, there will be military-specific needs that are not encompassed by these four types of commercial services:

- Geographically selected denial of high-precision global positioning information (sufficient for weapons delivery) to an opponent, and assured friendly access to those same services
- Assured access to communications that are covert and/or robust against jamming and tampering, including local surge capacity to deployed forces
- Assured relay of very-high-data-rate intelligence information from geosynchronous distances
- Day/night all-weather reconnaissance of low-contrast stationary and moving targets with hyperspectral imaging and in the shortest possible time

The proliferation of space applications at affordable prices will tend to offset the current US military edge. Capabilities in these military-specific areas will enable the US military to have the advantage over an opponent who is also exploiting the infosphere.

Space Technology Developments in the Commercial World in the Next Twenty Years

To deliver the services described above in a competitive environment, the commercial world will invest in bringing many technologies relevant to space to commercial viability. The technologies that the commercial world will develop are:

- Technologies for manufacturing many identical spacecraft
- Technologies for efficient spacecraft operations
- Low-cost high-performance electronics and computers
- Technologies for commercial global communications
- Small expendable space launch systems

- Systems-level simulation-based design
- Technologies for automated spacecraft checkout

These technologies will result in standardized, modular bus designs that can be launched on any compatible launch vehicle, simplified payload designs, commoditized payload elements, and efficient (e.g., autonomous) operations. In addition, the commercial world will develop management techniques to reduce system cost and delivery time as well as refining techniques for cost estimating and scheduling. Relying on the commercial world to develop these technologies, the Air Force will need to invest only where it is necessary to adapt these technologies to meet specific military requirements.

However, not all of the functions needed by the Air Force will be achievable solely with commercial developments.

Implications of the Vision for the Air Force in Space

The vision for the Air Force in space requires increased capability over projected commercial systems, yet these increases will need to come in a time of decreasing budgets. Therefore, the cost of space systems must be reduced to make these capabilities achievable. The costs of space systems are dominated by the costs of the individual elements, the costs to launch the space elements, and costs to operate them. Historically, the cost of space hardware has scaled directly with mass. To break the current cost paradigm in each of these areas it is necessary to invest in or to invest to adapt from the commercial world several key technologies. The relevant technologies are those that reduce the satellite mass for the same or increased functionality, technologies for launch vehicle cost reductions and performance improvement, and technologies for spacecraft automation.

Four Achievable Themes that Will Constitute the Vision for Space

With the attribute of affordable systems as an overarching consideration, space technology investments can be grouped under the four themes of Global Awareness, Knowledge on Demand, Space Control, and Force Application. These themes will be enabled by targeted investments by the DoD as well as related investments in the commercial sector.

Global Awareness

Global Awareness is the idea that space technology will enable the ability to see in near real time everywhere on the surface of the Earth or in the air or near space, under all weather conditions, at any time. The integration of this ability with the command and control system for a military operation will enable the US military to respond and out think any potential adversary in a context where space-based information will be available on a world wide basis. The timely acquisition and use of information will confer a tremendous advantage on US forces. Global Awareness also has enormous deterrent value. Any adversaries will know that they are under continuous surveillance by active and passive means at all times, under all conditions.

Global Awareness will be powerfully enabled by Air Force investment in technologies that will make possible large sparse apertures, evolving in the direction of clusters of cooperating satellites. Such clusters will enable aperture sizes that are bigger than those now only available

with large satellites. In addition, constellations of large numbers of smaller satellites will allow economy of scale in production and will have reduced vulnerability relative to single satellites. Also important to Global Awareness are the technologies for space-based active probing such as synthetic aperture radar (for day/night all-weather coverage) as well as technologies for passive probing through hyper- and ultraspectral sensors. These capabilities will enable any point on the surface of the Earth or the air to be scanned in over a wide range of electromagnetic bands.

Knowledge on Demand

Knowledge on demand is the idea that an individual warfighter could request knowledge about some area of operations. The warfighter has always benefited from having strong situational awareness in which he or she is called upon to fight. The human mind is very capable of assessing patterns in information and using those patterns to make decisions. As the infosphere envisioned by the commercial world develops, there will be a plethora of information available at many levels to US warfighters. Indeed, there will be so much information to collect, analyze, assess, synthesize and disseminate that the quantity will be overwhelming. What the warfighter needs is not information, but knowledge. Knowledge will come from a fusion of information from all types of sensor sources (air, ground, and sea as well as space) together with communications to deliver knowledge to the user.

The warfighter could request to see all the new threats in an area or an update on old threats or new targets. That request would be entered into a global integrated information system and if appropriate, a space-based set of sensors would provide the knowledge. The communication would be direct to the system, the request would be processed by the system, the data would be collected by the system, the knowledge would be extracted from the information gathered by the system, and that knowledge would be sent to the warfighter. This use of space-, air-, sea-, and ground-based assets combined with Global Awareness will enable direct and timely readout to tactical users. This integrated use of space-based assets is one of the aspects of information dominance and information warfare. The technologies that will enable Knowledge on Demand are the technologies of image processing, secure high-data-rate anti-jam communications, data fusion, artificial intelligence, neural networks, and distributed processing.

Space Control

The value of space systems and the advantages that they will give to the US will be so large that an adversary would be foolish not to target those space assets. In the next several years, the technology to selectively target an individual satellite will have proliferated all over the world and will be available to anyone at a relatively modest cost. Space systems can be targeted by a determined adversary with electronic warfare, high-power microwaves, lasers, and, as ballistic missile technology proliferates, with collateral nuclear weapons and kinetic-kill vehicles. The use of these degradation mechanisms can be made precise enough to allow a whole range of options ranging from temporary blinding of a sensor to permanent destruction of a sensor to physical destruction of a satellite. With this range of technology available in the world, it is important that the Air Force invest in the technologies for Space Control in a hostile environment. These technologies will allow US systems to survive and function in the kind of hostile environment that almost any adversary will be able to create in the future. The

distributed satellite systems necessary for Global Awareness and Knowledge on Demand will be inherently survivable since functions will be spread among many satellites.

Space Control can be divided into three technology areas: space asset surveillance, space asset negation, and space asset protection. It is important to know what assets are in space, to determine what capabilities they have, and to be able to distinguish them from background chaff and debris. The technologies that will enable effective space asset surveillance are sensor technologies. Once assets are identified, it may be necessary to undertake negation of an adversary's assets using directed energy, kinetic kill vehicles, or information warfare. The technologies that will enable space-based asset degradation are autonomy technologies that will enable a smart interceptor to be released from carrier spacecraft and then accomplish a mission to degrade a specific satellite without requiring ground control. However, it is also important to increase the survivability of friendly satellites. Space asset protection is necessary against both natural threats such as orbital debris and radiation as well as human-generated threats. Threats can be handled by making satellites hard to find, hard to track, and then hard to damage or kill. The technologies to substantially enhance survivability are low observable technologies and maneuvering technologies (which require high power). Space-based directed energy weapons for the protection of space assets will be enabled by the technologies of high power generation in space.

Force Application

The application of force from space to ground or air will be feasible and affordable in the next twenty to thirty years. Force Application by kinetic kill weapons will enable pinpoint strikes on targets anywhere in the world. Such force projection will enable Global Awareness to extend to global presence. The current Air Force mission area of Force Application includes both nuclear and conventional deterrents to place an adversary's terrestrial targets at risk. The technology for precision kinetic energy strike of fixed terrestrial targets from space-based or ballistic missile platforms is available to the US now. Technologies such as microelectromechanical systems (MEMS) could substantially improve the affordability of such systems. Technologies for similar conventional strike of mobile targets are possible given the appropriate targeting and command and control. Discussion of this kind of capability has so far focused on very limited capacity for a narrow range of targets. However, the technology suggests the possibility of a dramatic change in the means available for global power projection, making logistic delay negligible and recovering the investment in energy for logistic deployment directly as destructive energy on targets. The equivalent of the Desert Storm strategic air campaign against Iraqi infrastructure would be possible to complete in minutes to hours essentially on immediate notice. Force application by means of directed energy weapons will be feasible if the Air Force invests in the technologies for large amounts of power generation and energy storage. The technologies to enable this application will not be developed by the commercial sector and must be developed by the Air Force.

US perspectives on this kind of capability are colored by past investment in conventional force projection and by Cold War attitudes about deterrence. The use of ballistic missile platforms for conventional strike raises an ambiguity in nuclear deterrence that would have been destabilizing in the bipolar Cold War context. Use of orbital platforms for conventional strike

raises a similar ambiguity regarding verification of the treaty banning weapons of mass destruction in space. The opportunity for others to exploit this avenue to global power will be readily accessible to the large community of nations achieving access to space. Awareness of this opportunity should help motivate Air Force investments in Force Application and missile defense.

Recommendations for Investment in Space Technology

A combination of targeted Air Force investment and adaptation of commercial development will enable a revolutionary change in Air Force space capability. Such change in the next twenty years will be *affordable* and based around *Global Awareness, Knowledge on Demand, Space Control* and *Force Application.* Air Force technology investment must be carefully directed to provide the greatest return.

Revolutionary Technologies in Which the Air Force Must Invest

Several key technologies offer the possibility of a substantial increase in the exploitation of space by the Air Force, the potential impact of which is so great that the Air Force must invest now. The first three of these technologies will enable much larger payload fractions to be lifted to orbit by factors of four or more and, combined with affordable operations, will enable much cheaper access to orbit. Therefore they have the potential to revolutionize the launch equation and remove the significant barrier that high launch costs impose. These technologies are:

- High-energy-density chemical propellants to enable spacelift with high payload mass fractions—specific impulses of 1000 seconds or greater (in high-thrust systems) should be the goal of this effort
- Lightweight integrated structures combining reusable cryogenic storage, thermal protection, and self diagnostics to enable a *responsive* reusable launch capability
- High-temperature materials for engines and rugged thermal protection systems

The next two technologies will enable space-based weapons such as high power lasers, space-based radars with wide search areas, and satellites that can maneuver almost at will. They have the potential to substantially remove orbital dynamics as a barrier to where satellites can go. These technologies are:

- High performance maneuvering technologies such as electric propulsion (with thrusts greater than tens of Newtons, at specific impulses of thousands of seconds at near 100% efficiency, the goal for electric propulsion) and tethers for momentum exchange
- Technologies for high power generation (greater than 100 kiloWatts) such as nuclear power, laser power beaming, and electrodynamic tethers

The final set of technologies will enable a new vision for space applications where functionality is spread over many satellites rather than only in a single satellite. They have the potential to enable new applications from space (such as Global Awareness) at affordable cost. These technologies are:

- Technologies for clusters of cooperating satellites (e.g., high-precision stationkeeping, autonomous satellite operations, and signal processing for sparse apertures)

Evolutionary Technologies in Which the Air Force Should Invest

The Air Force should invest for evolutionary improvements in performance or reduced life-cycle costs to its systems. The technologies that offer such benefits are:

- Launch vehicle technologies
  - Engines, upper stages, and solar thermal propulsion
  - Vehicle structures (e.g., aluminum-lithium (Al/Li) or advanced composite tankage, as well as multifunctional structures)
- Satellite bus technologies
  - Structure technologies (e.g., lightweight structures, active vibration suppression, precision deployable structures, and software-controlled multifunctional surfaces)
  - Innovative energy storage technologies (e.g., the electromagnetic flywheel battery)
  - Attitude control technologies, including attitude sensors and attitude control system (ACS) algorithms
  - Radiation hardening technologies for spacecraft electronics
  - Low-observable technologies
  - Microelectromechanical systems (MEMS) technologies
- Sensor technologies
  - Large, sensitive focal plane arrays and associated readout and cooler technologies for hyper- and ultraspectral sensing of small low-contrast targets and long-wavelength detection against the cold background of space
  - Active sensor technologies (e.g., large lightweight antennas, high-efficiency radio frequency (RF) sources for synthetic aperture radar (SAR) and moving target indicator (MTI) radar, and high-energy lasers for lidar)
  - MEMS (including on-chip optics)
- Communications technologies
  - Very high-rate, long-distance optical communications
  - Multi-beam adaptive nulling antennas for anti-jam communications
- Data fusion technologies, including automatic target recognition
- Space-based weapons technologies

- Laser weapons technologies (e.g., large lightweight optics)
- Technologies for smart interceptors (e.g., autonomous guidance, MEMS)
- RF weapons technologies (e.g., lightweight energy storage) for electromagnetic pulse (EMP) and jamming

Commercially Led Technologies

Another set of technologies that will allow for evolutionary change in Air Force space operations will be driven by the commercial sector. These technologies merit minimal investment by the Air Force, yet the Air Force should invest as necessary to adapt these technologies to its needs. These technologies are:

- Small launch vehicles
- High-efficiency energy conversion and storage
- High-data-rate RF communications
- Technologies for debris reduction
- Information storage, retrieval, and processing technologies and protocols
- Image processing, coding, compression, and very large scale integration (VLSI) architectures
- Neural networks and artificial intelligence
- Technologies for spacecraft manufacturing
- Technologies for vehicle and spacecraft operations

Recommendations for Management Improvements

Space technology development occurs currently under NASA, DoD, NRO, DoE, and industry auspices. Execution of the resulting programs is only loosely coordinated through teaming, informal communication between investigators, professional society fora, and ad hoc topical organizations. Planning of the technology investment and programs by the various agencies is largely independent and uncoordinated. To create an efficient, coherent national space technology strategy, the Air Force should take the lead in establishing collaborative planning, advocating appropriate changes to US Space Policy, and encouraging coordinated execution of space technology development among all these organizations.

The chance to exploit commercial lead in some space technologies presents the opportunity for reduced government technology investment, reduced cycle time, and lower cost space systems. The ability to reap those benefits requires the discipline to accept the constraints of commercial capability in acquisition and in technology investment.

The recommended revolutionary and evolutionary technologies will provide the greatest benefit to the Air Force in the future and will not be developed by the commercial and civil communities. The least expensive route to meet future needs in space is a sustained government investment and continuity of effort.

Conclusions

The Space Technology Panel has determined:

- The international exploitation of space services will grow
- The Air Force will be able to take advantage of complementary commercial investment
- There are revolutionary technologies that will enable a new vision for the Air Force in space
- To effectively support the warfighter from space, active and sustained investment in these revolutionary technologies is essential

Contents

Illustrations

Tables